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ESTIMATE OF THE POSSIBILITY OF CONDUCTING MASS-SPECTROMETRIC  
MEASUREMENTS OF THE MATTER OF LUNAR SURFACE

by

V. E. Ivanova  
& A. N. Pudov

(USSR)



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ESTIMATE OF THE POSSIBILITY OF CONDUCTING MASS-SPECTROMETRIC  
ANALYSIS OF THE MATTER OF LUNAR SURFACE

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SUMMARY

A method is proposed for the determination of the chemical composition of the lunar surface with the utilization of a radio-frequency mass-spectrometer. The intake of matter in the analyzer chamber may be materialized by vaporization of lunar rock at electron-beam heating.

The processes of energy consumption are computed for the case of electron beam interaction with the lunar rock. The efficiency of the vaporization process is determined. The total power is evaluated, which is required for the vaporization of the necessary amount of matter for the mass-spectrometric analysis.

The technical requirements, imposed on a radio-frequency mass-spectrometer, are represented for the possibility of its utilization in the analysis of formations of cosmic objects.

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Mass-spectrometric analysis of lunar matter from a spacecraft soft-landed on the Moon may constitute one of the methods to obtain information on the composition of lunar rocks.

The conducting of such an analysis requires the erection of a complex equipment, consisting of a mass-spectrometer and a vaporizer assuring the intake of matter in the analyzer chamber.

The authors consider the possibility of using to that effect of a radio-frequency mass-spectrometer [1] with a vaporizer consisting of electron-beam gun. The block-diagram of the experiment is represented in Fig.1.

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(\*) OTSENKA VOZMOZHNOСТИ PROVEDENIYA MASS SPEKTRAL'NOGO ANALIZA VESH-  
CHESTVA LUNNOY POVERKHNOSTI.

For the solution of the problem introduced, radiofrequency mass-spectrometers are sufficiently accurate with enough resolution, while still responding to requirements set forth to devices installed aboard spacecrafts [2 - 4].

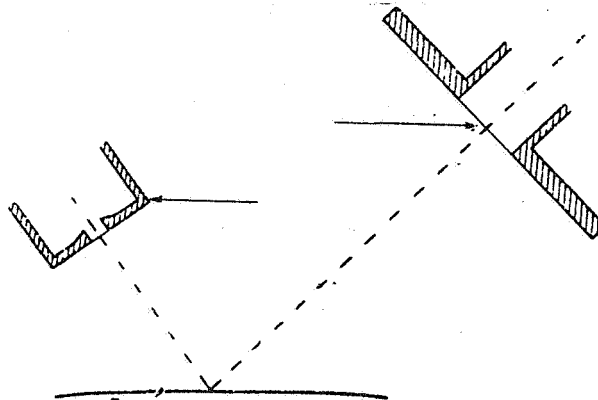


Fig.1 Block-diagram of the experiment

The choice of electron gun for the vaporizer is dictated by its peculiarities, advantageously featuring this source of energy: high energy density, electric current maneuverability and applicability in conditions of high vacuum. Moreover, electron-gun heating assures the total absence of contamination of matter vaporized.

The processes of matter vaporization under the action of an electron beam are at present insufficiently described from the theoretical viewpoint. This makes their computations somewhat difficult.

Presented in the current work are the results of some preliminary calculations allowing, in the first place, to evaluate the possibilities of the method, and, secondly, to create laboratory and airborne variants of the device.

### 1. VAPORIZATION OF MATTER BY ELECTRON BEAM

The power consumption  $W$  of the electron beam at its passage through the matter takes place as a result of the following processes: heating, melting and vaporization of matter, propagation of heat from the place of ray incidence as a result of heat conductivity, temperature emission, ionization and excitation of vaporized atoms found to be in the path of the electron beam.

The calculation of power distribution by the indicated processes and the total power of electron beam required for the vaporization of the mass of matter from the rock's surface, ensuring mass-spectrogram recording by the device, are determined for the fundamental types of rocks - granites, basalts, dunites and chondrites.

### Loss of Power to Temperature Radiation

The power consumption  $W_1$  to temperature radiation was estimated from the Stefan-Boltzmann law, assuming that the radiation takes place from the vaporizing surface  $S$  of  $1 \text{ mm}^2$  area at temperature  $T \sim 4000^\circ\text{K}$ .

$$W_1 = \varepsilon \sigma T^4 S, \quad (1)$$

where  $\varepsilon$  is the coefficient taking into account the thermal emissivity ( $0 < \varepsilon < 1$ ),  $\sigma$  is the Stefan-Boltzmann constant. Calculation for  $W_1$  yields the quantity of  $1 \text{ w}$ .

### Loss of Power to the Ionization and Excitation

The loss of power to ionization and excitation as the electron beam traverses the cloud of vaporized matter is estimated from the expression

$$W_2 = \int_{r_0}^{r_{\max}} \rho \frac{dE}{dR} dr + \frac{dE}{dR} \rho_0 r_0, \quad (2)$$

where  $\rho$  is the density of matter in the vaporized flow. For our case

$$\rho = \frac{\dot{m}}{\frac{1}{3} \pi r^2} \cos \varphi \sqrt{\frac{M}{2kT}}, \quad (3)$$

where  $\dot{m}$  is the rate of matter vaporization from the surface, in g/sec;  $M$  is the mass of one molecule, in g;  $dE/dR = 30 \text{ kw cm}^2/\text{mg}$  is the loss of power over the electron path unit [5];  $\varphi$  is the incidence angle of the electron beam to the surface;  $r_0$  is the radius of the spot from which vaporization takes place;  $r_{\max}$  is the distance from the electron gun to the vaporization surface;  $\rho_0$  is the density of matter near the vaporization point.

The required rate of vaporization  $\dot{m}$  was estimated from the condition that a gas cloud must be forming at the place of location of the mass-spectrometer; this gas cloud must have a density assuring the normal operation of the device (the range of operation pressures of the mass-analyzer is  $10^{-4}$ – $10^{-6}$  mm Hg).

Taking into account the Lambert cosine law from the distribution in space of particles vaporizing from an ideal surface, the number  $N_1$  of particles entering the mass-spectrometer per unit of time is

$$N_1 = 2n \frac{\Delta S}{S} \cos \varphi = n \frac{d^2}{4R^2} \cos \varphi, \quad (4)$$

where  $n$  is the number of vaporized particles per sec;  $\Delta S$  is the useful area of mass-spectrometer's slot;  $S$  is the surface of the hemisphere, where vaporization takes place.

On the other hand, from the correlation for the number of particles of ideal gas permeating an area of diameter  $\underline{d}$ , at pressure  $\underline{p}$  and temperature  $T$ , we may write for the number  $N_2$  of particles entering the mass-spectrometer per unit of volume

$$N_2 = n_0 \frac{c \Delta S}{2 \sqrt{3}} = \frac{pc \Delta S}{2 \sqrt{3} kT} \quad \left( n_0 = \frac{p}{kT} \right), \quad (5)$$

where  $n_0$  is the number of particles in  $1 \text{ cm}^3$ ;  $c = \sqrt{2kT/m}$  is the most probable velocity of molecules.

Equating  $N_1$  (4) and  $N_2$  (5), we find  $\underline{n}$ , that is, the number of particles vaporizing in 1 sec.

$$n = \frac{p 9000 \cdot 4 R^2}{kT \cos \varphi}, \quad (6)$$

for  $R = 30 \text{ cm}$ ,  $\varphi = 45^\circ$ ,  $n = 0.8 (10^{17} - 10^{19})$  particles/sec.

Passing to the vaporized mass for various rocks, we obtain:

$$\begin{array}{ll} \text{for granite} & m = 0.75 \cdot (10^{-5} - 10^{-3}) \text{ g/sec,} \\ \text{for basalt} & m = 0.75 \cdot (10^{-5} - 10^{-3}) \text{ g/sec,} \\ \text{for dunite} & m = 0.6 \cdot (10^{-5} - 10^{-3}) \text{ g/sec} \\ \text{for chondrite} & m = 0.6 \cdot (10^{-5} - 10^{-3}) \text{ g/sec} \end{array} \quad (7)$$

Utilizing the found values of  $\underline{m}$ , from (3) and (2), we obtain the value of power loss  $W_2$  of the electron beam to excitation and ionization. It constitutes  $\sim 10^{-2}$  percent of energy fed.

#### Loss of Power to Heat Conductivity

The loss of electron beam power as a consequence of heat conductivity of matter was estimated from the general solution of heat conductivity equation for the case of heat propagation from a point source in an unbounded space [6]

$$T_t - a^2 \Delta T = \frac{f}{c\rho}, \quad T(r, 0) = 0, \quad (8)$$

where  $T(r, t)$  is the temperature of the point  $M(x, y, z)$  at time  $\underline{t}$ ;  $a^2 = k/c\rho$  is the thermal conductivity coefficient (for rocks  $a^2 = 0.006$ );  $\underline{c}$  is the specific heat capacity;  $\rho$  is the density of matter;  $\underline{f}$  is the density of thermal sources. In our case  $f = W_0 \delta(r - r_0)$ , where  $\delta$  is a delta-function;  $W_0$  is the power of the electron beam reaching the surface.

The solution of the given problem is represented in the form

$$T(x, y, z, t) = \int_0^t \int_{-\infty}^{+\infty} \int_{-\infty}^{+\infty} \int_{-\infty}^{+\infty} \frac{2}{c\rho} G(x, y, z, t, \xi, \eta, \zeta, \tau) d\xi d\eta d\zeta d\tau \times \\ \times f(\xi, \eta, \zeta, \tau) d\xi d\eta d\zeta d\tau, \quad (9)$$

where  $G$  is a function of point source's thermal influence

$$G = \left( \frac{1}{2\sqrt{\pi}a^2(t-\tau)} \right)^3 \exp \left[ - \frac{(x-\xi)^2 + (y-\eta)^2 + (z-\zeta)^2}{4a^2(t-\tau)} \right] \quad (10)$$

Integration of (9) leads to the expression

$$T(r, t) = \frac{W_0}{4\pi^{3/2}ak} \int_0^t \exp \left[ - \frac{r^2}{4a^2(t-\tau)} \right] \frac{1}{(t-\tau)^{3/2}} d\tau. \quad (11)$$

After substitution of variables  $4a^2(t-\tau)$ , we obtain for the distribution of temperature the expression

$$T(r, t) = \frac{W_0}{\pi \sqrt{\pi} \cdot k} \int_0^{2a\sqrt{t}} \frac{1}{u^2} \exp \left[ - \frac{r^2}{u^2} \right] du. \quad (12)$$

The temperature distribution (12) allows us to evaluate the energy  $W_3$  of the electron beam consumed to heat the matter as a consequence of the heat conduction process:

$$W_3 = c\rho \int_r^\infty T 2\pi r^2 dr. \quad (13)$$

The quantity of energy consumed on the vaporization and irradiation is

$$W_0 - W_3 = c\rho \int_0^r T 2\pi r^2 dr = \frac{2W_0}{\sqrt{\pi}a^2} \int_0^r \int_0^{2a\sqrt{t}} \frac{r^2}{u^2} \exp \left[ - \frac{r^2}{u^2} \right] dr du = \\ = \frac{W_0}{2a^2} \int_0^{2a\sqrt{t}} u \left[ \Phi \left( \frac{r}{u} \right) - \frac{2}{\sqrt{\pi}} \frac{r}{u} \exp \left[ - \frac{r^2}{u^2} \right] \right] du, \quad (14)$$

where  $\Phi \left( \frac{r}{u} \right) = \frac{2}{\sqrt{\pi}} \int_0^{r/u} \exp \left[ - \frac{r^2}{u^2} \right] d \left( \frac{r}{u} \right)$  is the integral of errors,

or

$$\frac{W_0 - W_3}{W_0} = \frac{1}{2a^2} \int_0^{2a\sqrt{t}} u \left[ \Phi \left( \frac{r}{u} \right) - \frac{2}{\sqrt{\pi}} \frac{r}{u} \exp \left[ - \frac{r^2}{u^2} \right] \right] du. \quad (15)$$

For the estimate of the quantity  $(W_0 - W_3)/W_0$ , we shall substitute in place of the integral in expression (15)

$$\frac{W_0 - W_3}{W_0} = \frac{2}{m^2} \sum_c n \left[ \Phi \left( \frac{r}{n\Delta u} \right) - \frac{2}{\sqrt{\pi}} \frac{r}{n\Delta u} \exp \left[ - \frac{r^2}{n\Delta u} \right] \right]. \quad (16)$$

Bearing in mind that a volume of matter of radius  $r_0$  evaporates in a unit of time, and that during the time  $t$  the volume of evaporating matter would have a radius

$$r = r_0 \sqrt[3]{t}$$

and taking the value  $t = 25$  sec (considering that after 25 seconds the distribution of temperature over the surface follows the same law as does the distribution of temperature from a point source), we obtain

$$\frac{W_0 - W_3}{W_0} \approx 8\%.$$

Crawford brought up in [8] the value of the efficiency of electron-thermal processing of iron, say 0.083%, for a power of electron beam of 90 w. Taking into account that the heat conductivities of metals are by two orders higher than those rock matter, the evaluation of the efficiency of electron-thermal vaporization of rocks obtained by us, is not in contradiction with Crawford data.

#### Power Consumption to Vaporize Matter

To vaporize a specific quantity  $m$  of matter, determined by us in (7) as that specifically required, the necessary energy  $W_4$  (the maximum value is taken):

for granite	1200 · 0.75 · 10 <sup>-3</sup> cal	≈ 4.0 w	
basalt	1300 · 0.75 · 10 <sup>-3</sup> cal	≈ 4.2 w	
dunite	1200 · 0.6 · 10 <sup>-3</sup> cal	≈ 3.0 w	
chondrite	1100 · 0.6 · 10 <sup>-3</sup> cal	≈ 3.0 w.	(18)

(1200, 1300, 1200, 1100 cal/g being respectively the specific heat for the vaporization of granite, basalt, dunite and chondrite [7].

#### Total Power of Electron Beam Required to obtain a mass-spectrum

The total power of the electron beam is obtained by summing up the consumptions of power on all the above described interaction processes of the electron beam with the matter

$$W = W_1 + W_2 + W_3 + W_4. \quad (19)$$

Let us estimate its value. From (17),  $(W_0 - W_3)/W_0 = (W_1 + W_4)/W_0 = 0.08$ , assuming that  $W_4 = 3.5$  w,  $W_1 = 1.0$  w, we obtain  $W_0 = 56$  w.

Since  $W_2$  - power consumption on the ionization - constitutes  $\sim 10^{-2}\%$  of the energy supplied, we may neglect it and thus the total power consumption is

$$W = W_0 \approx 56 \text{ w.}$$

## 2. TECHNICAL REQUIREMENTS SET FORTH TO THE MASS SPECTROMETER

The basic characteristics of the radiofrequency mass-spectrometer (MX6407M) manufactured by our industry, are presented in the work [4].

In order to evaluate the suitability of the device for the analysis of rocks, one should examine Figures 2 and 3. Fig.2 represents the expected lines in the basalt mass-spectrum in the assumption of presence in the analyzed beam of atomic and molecular ions and all possible dissociation debris. Reference spectra of the MX6407 device are shown in Fig.3.

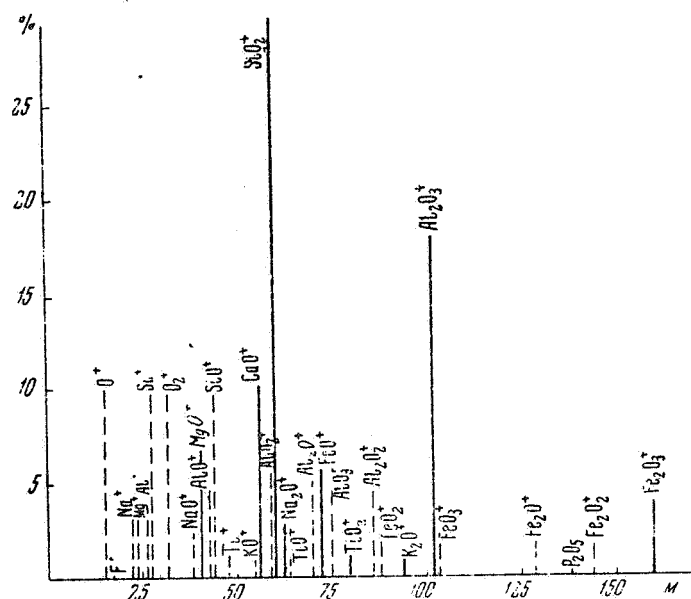


Fig.2. Presumed mass-spectrum of basalt

It may be seen from the figures type-MX6407 r-f mass spectrometer can be used for analysis of rocks on the condition of widening the registered band of mass numbers to 160 amu with resolution increase in the region of average atomic weights (50 - 75 amu, where there is density maximum of spectral lines) to 40 - 60 amu.

The minimum registrable element content in rocks is estimated from the partial threshold response of the mass-spectrometer ( $3 \cdot 10^{-11}$  mm Hg by hydrogen). It constitutes 0.1 - 0.001 % of matter by weight (depending upon the probability of ionization of vaporized particles).



The dynamic range of the device being  $10^3 - 10^4$ , it was possible, by response cutover, to register not only the elements with small content, but also those constituting the bulk of rock mass.

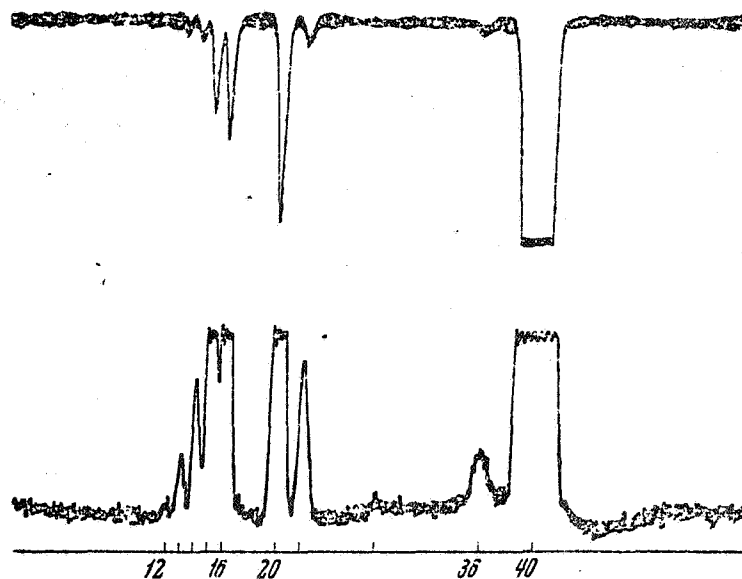


Fig.2  
Reference spectrum of gas mixture filling the analyzer  
of MW6407

### CONCLUSIONS

1. The mass-spectral analysis of lunar surface matter may be carried out with the use of a radiofrequency mass-spectrometer of the type MX6407M with extension of the range of registered mass numbers to 190 amu, and increase of response in the average atom weight region to 40 - 60. The intake of matter in the analyzer chamber may be realized by vaporization of rock's surface material by an electron beam of 60 w. power. The same device may serve for measuring the atmosphere of the Moon (without inclusion of electron gun).

2. The fundamental process of energy consumption at electron beam interaction with the rock is the heat conduction; about 90 to 92 percent of ray energy is lost to heating the matter outside the vaporized volume. The useful energy consumption to vaporization constitutes 6 to 8 percent. The loss of power to ionization and excitation of molecules of the vaporized matter constitutes  $10^{-2}\%$  of energy supplied. The loss of power to ionization and excitation of molecules of vaporized matter (at  $T = 4000^\circ\text{K}$ ) is  $\sim 1$  w. The total power, necessary to vaporize the quantity of rock required for mass-spectral analysis constitutes 85 to 100 w.

\*\*\*\* THE END \*\*\*\*

References follow../..

ST-ACH-LS-10755

R E F E R E N C E S

- [1]. W. H. BENNETT. J. Appl. Phys., 21, 2, 1950.
- [2]. V. G. ISTOMIN. Sb."ISZ" (AES), v. 3, p.98, 1959.
- [3]. V. A. PAVLENKO, A. E. RAFAL SON, M. D. SHUTOV. Kosm.Issl. 1, 2, 287, 1963.
- [4]. V. A. PAVLENKO, B. I. ZARKHIN, A. E. RAFAL SON, M. E. SLUTSKIY. Ib. 4. 3, 457, 1966.
- [5]. J. R. YOUNG. Phys. Rev. 103, No.2, 1956.
- [6]. A. N. TIKHONOV, A. A. SAMARSKIY, Uravneniya matematicheskoy fiziki Math.Physics Equations). Izd"NAUKA", 1966.
- [7]. L. V. GUREVICH, G. A. KHACHKURUZOV, ET AL. Termodinamicheskiye svoystva individual'nykh vesh(Thermodynamic Properties of individual matters) Izd.AN SSSR, 1962.
- [8]. VVEDENIYE V TEKHOLOGIYU ELEKTRONNO LUCHEVYKH PROTSESSOV, Red.Ol'shansk. IIntroduction to Electron Beam Processes' Technology). Izd. "Metallurgiya", 1965.

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